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Approach to physical concepts in preschool and primary school

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Summary. — The aim of this paper is to present the results of some physics experimentations carried out in preschool and primary schools by university students in "Scienze della Formazione Primaria" during the preparation of their master theses. The main idea of the proposed activities is to test how the suggestions of the recent didactic research concerning new approaches to physical concepts and new didactic methodologies can promote the young pupils reasoning and learning process. In this paper the experimentations are analyzed using the rich documentation provided in the thesis through the drawings of the pupils and the records of the verbal and written expressions, often obtained by audio and video registrations. The presented results provide also new indication useful for the future didactic research.

PACS 01.40.Fk – Research in physics education.
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1. – Introduction

As underlined in the last issue of the Italian primary school curricula [1], an early introduction of scientific education is very important because it promotes the development of logic, language and problem-solving skills, producing individuals who can think and act in an independent way [2]. In the last four years the Turin physics didactic research group guided more than one hundred experimental master theses, performed by university students of "Scienze della Formazione Primaria", aimed to the introduction of "science" in classes of preschool and primary school. The students, who in the following will be briefly called "tutors", with the support of the research group, deeply investigated the suggestions provided by the recent didactic research in terms of approaches to physical concepts, didactic methodologies and child's reasoning and learning process. Then, they defined the physics topic, the schedule of lessons and the didactic methodologies. The tutors had also to share their proposals with the teachers of the classes in which they operated and had to take into account the specific context of the class.

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The focus of didactic experimentation was on two main questions:

- Is it possible to teach physics concepts to 4 to 11 years old pupils?
- In which way the recent developments in science education, can be integrated in teaching and learning methods already used by the class teachers?

The activities have been extensively documented paying attention to the audio and video registrations and the collection of drawings, posters, training aids and simple objects realized by pupils.

2. – Methodological approach

Children bring to school their own experience of the natural word and other information that they have learned from previous experiences. Therefore, in order to introduce a new "physical concept", all the experimentations in the classes started from children's prior conceptions. Then, suitable learning environments were provided to facilitate the process of transformation, development and enrichment of knowledge, skills and concepts. The proposed activities also encouraged the acquisition of appropriate scientific terminology and tested the children ability to use the new concepts in different contexts. Taking into account the suggestions provided by the recent didactic research, different teaching and learning methodologies were used.

The *storytelling* was demonstrated to be effective to introduce a new topic, in particular with 4-6 years old children. The characters of the story involve the children in their adventures stimulating their curiosity and imagination. In addition, the story gives usually a great number of suggestions to plane the subsequent activities. As an example, the characters of the story can guide the children in manipulative activities as well as in explorative ones using their senses. At higher school levels (7-8 years), the same methodology was used to evoke children's emotions and previous knowledge related to the topic under investigation. Finally, with 9-10 years old children, the story was used to conclude the activity: each child, in fact, writing a story, could demonstrate if he/she acquired the new concepts and knowledge or if there were still some difficulties.

Starting with a *brainstorming* was often used in the primary school in order to stimulate children's previous ideas and knowledge. This method helps to focus on the topic being discussed, stimulates the flow of thoughts and of spontaneous connections with previous experiences, it is "democratic" and builds confidence and creative thinking. At first, the topic was clearly stated and the children were invited to give their responses, then the ideas were listed quickly without any discussion; finally, once the discussion slowed down, the ideas were compared and discussed. Sometimes the questionnaire was also a good method to stimulate the children prior concepts and to reveal children's mental and interpreting models.

As regards the activities at preschool level, children were mainly involved in *spontaneous learning experiences* [3]. The children were led to explore with their senses the world or the new situations arranged by teachers: they looked, touched, smelled, listened and tasted. At the same time, the children began also to apply basic concepts to collect and organize data, mainly through sketches, and to answer simple questions.

At the level of primary school, the laboratory activities realized through *informal learning experiences and/or structured learning experiences* were demonstrated to be effective. The children had the opportunity to make hypotheses, to ask and answer questions, to do investigations and to learn how to apply problem solving skills [4].

Moreover, activities of increasing complexity encouraged the development of reasoning process and knowledge. Sometimes, in these contexts, it was helpful to use different strategies, such as cooperative learning, peer education or tutoring, and to encourage the discussion between the children or between children and teacher. In fact, the discussion helps students to organize the ideas, puts in evidence the process of knowledge acquisition and improves also the social skills. For this reason the author underlined the importance to document all the activities paying attention especially to audio and video recording of the dialogues.

The *role play* [5] and the *dramatization* are considered good methods to create interest for science both in preschool and in primary school. The children make the experience to be active part of a story or of a situation or of a discussion, engaging themselves into a scenario. In the experimentations discussed in this paper these methodologies were used at the end of the activity with the aim to verify the children's scientific knowledge and skills.

Among the methodologies suitable to test the development and the enrichment of children's knowledge and concepts there is also the *scientific drawing*. In some experimentations it was used at the end of the activity to help the children to focus their attention on what they had observed and done. The interesting aspect is that often, indirectly, also the children's "abstract" thoughts and interpretations filter in the drawings [6]. Eventually the teacher could require further clarifications to the pupils in order to investigate more deeply what they had in mind. Sometimes the "scientific drawing" was proposed at the beginning of the activity to investigate the children's mental models and also in this case, when an inconsistent model appeared, further explanations were asked by the teacher.

3. – Physics concepts

The aim of this section is to summarize the physics concepts experimented in preschool and in primary school. In particular the attention will be focused on the educational goals at different scholar levels.

The approach to the *length measurement* is a topic rather common in preschool and in primary school. Children are usually able to say if an object is longer than another object or if a child is taller than another one. For this reason with 3-5 years old children the activities were mainly based on objects (more than two) comparison and classification. With 5 years old children it was also possible to introduce an arbitrary length unit (felt-tip pen, plastic tap, strip). The results of the experimentations showed that 5 years old children were already able to use the arbitrary unit to measure an object although they had then difficulties to describe the measurement procedure and to express the final result [7]. At higher scholar levels, the activities were focused to introduce the International System of units: starting with a historical approach based on units related to the dimensions of the human body, it was possible to create with children an arbitrary unit system, showing finally the need of a conventional "international" system of units.

Different approaches can be used to introduce the concepts of *heat* and *temperature* [8]. With 3-5 years old children the activities were based on thermal sensations: children touched an object or dipped their hands into different containers filled with water at different temperature and described the thermal sensation they experienced. Primary school children usually know the thermometer, so the experimental activities were addressed to learn the characteristics of the instrument and understand how to use it. Moreover, the children learned to collect and organize temperature measurements in tables or graphs which help to obtain useful information concerning the thermal process. The children were involved in planning simple experiments to discover, for example, the effect of different insulating materials on the melting rate of ice or the effect of heating on air volume.

A great number of didactic projects concern the properties of *air* and *water*. In preschool the children's attention was mainly focused on the discovery of water characteristics (volume, temperature). At this scholar level, the manipulative approach was fundamental as well as the observation of different objects or substances behavior inside water (buoyancy, solubility). At primary school level, suitable learning environments were set to deeply investigate the fluid properties and to introduce, in a qualitative way, some physics laws (Pascal, Stevin, Archimedes, Boyle). The use of elementary objects, such as bottles, syringes or balloons, allows to visualize the physical concepts and encourage the phenomena interpretation.

In the primary school very often the teachers present didactic projects on *electric phenomena* based on simple experiments on static electricity and on electric circuits [9]. The goal of the activities on static electricity proposed in one of the theses which were analyzed, was to reproduce in a "controlled environment", with simple objects, some phenomena that children observe spontaneously every day. To encourage children's participation some questions were proposed, as

– Have you ever walked across the room to pet your dog, but got a shock instead?
– Have you taken your hat off in a dry winter's day and had a "hair raising" experience?
– Have you made a balloon stick on the wall after rubbing it against your clothes?

Then simple experiments were realized by using everyday objects such as: balloons, drinking straws, plastic cutlery, small piece of paper, aluminum balls and heather. In order to explain these phenomena, the teachers often refer to the microscopic structure of matter using images and simple sketches on the blackboard or dramatization activities. Concerning the electric circuits, it has to be taken into account that today the majority of children grows up in a technological environment, which includes a variety of appliances operated by electricity. The experimentation carried on in the classes showed that many primary school children are already able to set up an electric circuit and that they have their own models on electricity/electric current. The activities on this topic aimed to identify and to investigate the main components of an electric circuit: batteries or power supply, live wire or conductor materials, switch, light bulb or buzzer, "series" or "parallel" circuit. The project of the electrical system for a small wood house increased the children's participation and interest in the physical concepts involved. Finally, the hazards relative to the use of electricity were discussed collectively.

With 3-6 year old children a simple approach to *magnetic phenomena* was experimented. Several magnetic games were provided to children who spontaneously explored the magnetic attraction or repulsion. In the same way they investigated which materials were attracted by magnets and experimented with the sense of touch the strength of magnetic fields. At higher school levels, more complex experiments were arranged. As an example it was possible to visualize the direction of the magnetic field using a compass or iron filings and to "quantify" the strength of a magnetic field determining how many paper clips or coins can be held in a chain by different magnets.

The *light* and its characteristics is a topic commonly investigated in primary school. Different experiments were set up to explore the light propagation: the differences between a natural light source and an artificial one, the interaction between the light and different objects, the formation of shadows, the reflection, the refraction and the dispersion, as it appears, for example, in the rainbow. As expected from the results of many researches on children's models regarding the mechanism of vision [10], a wide variety of spontaneous models emerged among the children who took part in the experiments, in general different from the canonical model according to which light is emitted by a primary source and it is diffused by a secondary source: this triggered sometimes further investigations by the tutor or by the teacher, always done without influencing the answers of the children.

Many activities planned in the primary school were related to the *energy*, which is considered a complex and abstract concept, though being something that belongs to the everyday life [11]. The experimentations focused on the different types of energy and on energy transformations starting from children's everyday experience. Different simple objects were used, such as catapults, slings, spring loaded cars or specific toys. Also in the activities on electric, magnetic and thermal phenomena the transformations and transfers of energy were always investigated. Through these concrete activities it appeared rather clearly that the children can recognize the typical characteristics of the energy, even if they are not able to explain what the "energy" is.

4. – Results of experimentations

Two experimentations carried out in primary school will be described in details.

4·1. *Multidisciplinary approach to length measurement.* – The first experimentation concerns an approach to length measurements experimented in a small school located in the Piedmont mountain region in a "pluriclass", that is in a class with children from 8 to 10 years. The activities were realized mainly with the 9 years children with an approach which involved different disciplinary areas (geography, history, logic, mathematics) and different methodologies (problem solving, cooperative learning, role play and dramatization).

This experimentation focused on the concept of measurement unit and on the measurement procedure. In particular the activities started from the identification of arbitrary length units and pointed to identify the need to use common units in an international unit system. The activities were organized using a concrete approach and exploiting real problems and situations.

The first didactic experience concerned mathematical and geographical areas with the aim to guide the children to understand the need to measure and to rescale the objects in order to correctly reproduce them, for example, on a piece of paper. The preliminary discussion between the children and between them and the tutor started from two questions:

– How is your class?

– Which furniture are inside?

The children concluded that they could describe the class verbally or that they could make a drawing it. The children's sketches were very different: some reproduced the class from the top, others from the side, without taking into account the correct ratio between the objects, as is shown in fig. 1.

The next discussion was focused to discover the most appropriate point of view to make the drawing of the class and to choose the suitable length unit in order to measure the furniture. The children identified naturally the tiles of the floor as the most appropriate length unit to measure the objects as displayed in fig. 2; then they also tried to use other units such as a pen or a pencil (fig. 3).

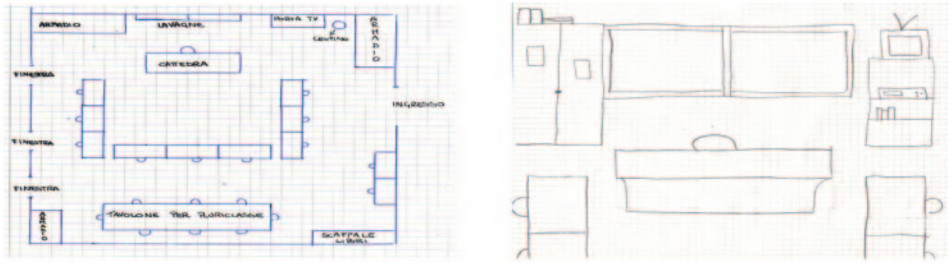

Fig. 1. – Martina's drawing (on the left); Michele's drawing (on the right).

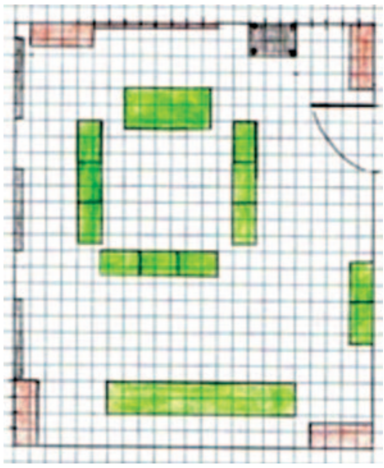

Fig. 2. – Map of the class: a square corresponds to a tile of the floor.

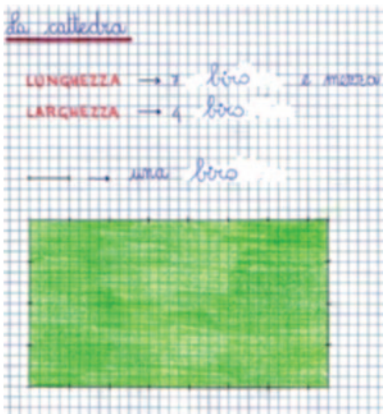

Fig. 3. – Measurements of the desk length using pens: length = 7.5 pens, width = 4 pens.

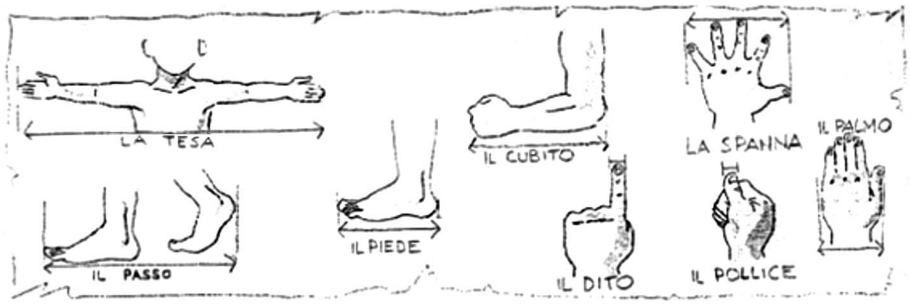

Fig. 4. – Ancient body unit: toise, cubit, span, step, feet, finger, inch, palm.

Later on, the tutor proposed an activity in the historical area with the aim of showing the use of body units in the ancient population (fig. 4) and the natural evolution toward common length units. The children talked about the Egyptian culture, the body units used by the population and the problem of re-establishing the field boundaries after a flood of the Nile. The tutor proposed to the children a dramatization activity: the children had to re-establish the field boundaries after a flood of the Nile using the cubit as length measurement unit. At the end of the activity the children noticed that the dimensions of fields were different:

Alice: The fields are not of the same size. Michele's field is bigger than the others.

Martina: It is not right, Michele is the tallest guy of the class and his cubit is the longest one.

Michele: We could use always my cubit, in this way all the field sizes should be the same.

Tutor: You are right. But do you have other ideas?

Martina: We could use a stick like this. All the farmers come here, take an object of the same length of the stick, then they can measure their field.

The dialogue puts in evidence how the children naturally recognized the importance of using a common unit of measurement (the same object - stick) to obtain fields of the same size.

To consolidate and verify the acquisition of new concepts, the experimentation continued in the scientific-mathematic area. In particular the activities were addressed to underline all the steps required in the measurement procedure. The children were involved in the measurement of different objects or parts of the school, such as the corridor length, the gym width, the dimensions of the class, using arbitrary units (objects) or body units.

Then, all the children of different ages participated at a role play organized by the tutor (fig. 5). The class was modified into a market and two stands were prepared. In both stands the children could buy fabric at 5 euro/toise (see fig. 4). Two children were chosen as sellers: *Amedeo*, the taller one of 10 years, and *Giosuè*, the smaller one of 6 years; all the other children had to decide where to buy the fabric. While children of 10 years and some of the 9 years old had no doubts that it was much more convenient to buy fabric from Amedeo (broader toise), the others did not understand the differences between the two stands.

Enrico (8 years): I don't understand the difference between the two stands, the price is the same.

Andrea (8 years): In my opinion there should be something different, otherwise there will be only one stand.

Fig. 5. – Children's drawing of the role play.

Tutor: Which is the measurement unit used? I mean, what do Amedeo and Giosuè use to measure the fabric?
Enrico (8 years): Maybe I understood. Amedeo toise is broader than Giosuè one because Amedeo is taller.
Andrea (8 years): You are right, the difference between Amedeo and Giosuè is evident.
Lorenzo (10 years): If Amedeo measures the fabric with the toise we will buy more fabric at the same price.
Sara (9 years): On the contrary, Giosuè is smaller than Amedeo, therefore Martino and Agostino have bought the less convenient fabric.
Michele (9 years): They bought less fabric than us.
Lorenzo (10 years): If they wanted to buy the same quantity of fabric we bought, they had to spend much more money.
Linda (10 years): They have to use the meter.
Nicole (10 years): When I go to the market with my mum, the sellers use the meter, they don't use the toise.
Michele (9 years): It is not correct to use body units since everybody is different.
Andrea (9 years): If we use the meter the measurement procedure is also faster.

The dialogue underlines how, through the discussion, all the children understood the differences between the two stands. In addition, at the end of activity, they recognized the importance of using a common length measurement unit recalling naturally the meter as more convenient unit. This activities provided also the basis to introduce the meter and the international unit system.

4˙2. *Approach to electric potential difference.* – The second experimentation was carried out with 10 years old children and concerns an approach to energy transformations related to the electric potential difference. This concept is quite complex, even at higher scholar level, for this reason an innovative approach at this argument was proposed. In particular the idea was to connect the presence of a gradient of a physical quantity (temperature, altitude, pressure, electric potential . . .) with the effects in terms of energy transformations and transfers.

In the proposed activity the idea was to discuss on the effect due to an altitude difference exploiting children prior conceptions. After a preliminary brainstorming on "altitude difference" children looked for the meaning of the word "difference" in the vocabulary. Then, they tried to identify altitude differences in the sports and in their everyday life. Children found an altitude difference when going up or down, for example,

Fig. 6. – The effect of an altitude difference explored using a small ball and a wood slide.

in the mountain, and mentioned also their feelings in these situations: the effort when they go up and the opposite one when they go down.

Then, the children observed and described the effect of the altitude difference on the motion of a small ball when it goes down or up along a wood slide (fig. 6). The children analyzed the situation also in terms of energies involved and transformations. In addition they interpreted the altitude difference in terms of distance between a higher point, labeled with +, and a lower one, labeled with -.

Since the goal of the didactic experience was a precocious approach to the electric potential difference, the experimentation continued through the analysis of batteries of different shape and voltage. The children summarized in a poster the batteries characteristics and tried to identify the common elements: it is always possible to see two symbols (− and +) and a number followed by a symbol "V". The tutor simply declared that this symbol "V" (that means volt) corresponds to the electric potential difference characterizing each battery. The critical point was to compare and connect the two situations previously explored:

– (a) the altitude difference is always identified by a number with a length measurement unit; it is always possible to identify a higher point (+) and a lower one (−). (b) The altitude difference produces useful effects and allows some energy transformations.

– (a′) The electric potential difference, readable on each battery, is expressed by a number followed by the symbol V (volt). It is always possible to identify two parts labeled with + and −.

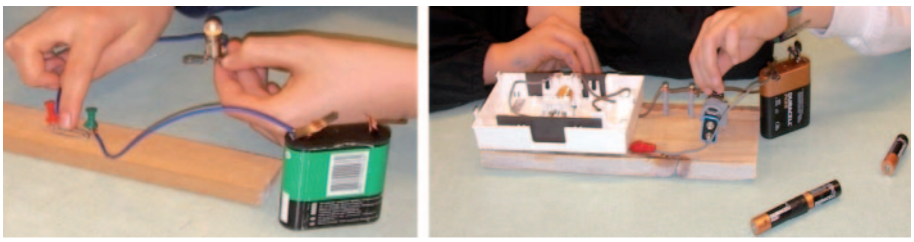

Fig. 7. – The children arrange simple electric circuits (with a lamp on the left and with a buzzer on the right) and experiment the effect of various potential differences.

The discussion between the pupils and tutor focused on the following question: (b′) "Is the electric potential difference able to produce useful effects and does it allow some energy transformations as the altitude difference?" In order to investigate this question the children attention was focused on the visible effects related to an electric potential difference. Different laboratory activities were proposed. The children had the opportunity to arrange simple electric circuits with lamps, buzzers, fans or metallic wires exploring the effect of various potential differences and investigating the energy transformations from electric energy to light, sound, motion or thermal energy (fig. 7).

5. – Conclusions

The results of these experimentations underlined that using suitable didactic methodologies and new approaches, as suggested by the recent didactic research, also abstract physical concepts can be experimented in preschool and in primary schools. In particular, the author wants to underline the importance of documenting all the activities mainly through the records of the verbal and written expressions, possibly obtained by audio and video registrations. In this way it is possible to observe the evolution of the children's thinking and of their spontaneous models and, in general, to evaluate the success or the failure of the experimentation, showing the strong points as well as the weak ones.

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